Power Control of DC Microgrid With Variable Generation and Energy Storage

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Abstract

Power control strategies of DC Microgrid with variable generation and energy storage was presented in this paper. The DC microgrid consists of PV panel ,wind turbine, battery, dc loads and a grid–connected inverter system. In order to ensure the stability of a DC microgrid, the power flow within the DC microgrid must be balanced at all times to maintain a constant dc bus voltage. Different with the centrally control method , the droop control based on the dc-bus signalling(DBS) technique is used in this paper. When the load power variation or ac grid fault, the bi-directional grid converter or battery need to adjust the power balance during grid-connect condition or island condition. MATLAB/SIMULINK simulations are presented to demonstrate the feasibility of the proposed power control strategy during various operating conditions.

Keywords

DC microgrid; renewable source; power management; DC Bus Signalling

Introduction

Due to increasing concerns on a generic intergrid concept, microgrid has attracted extensive interest. A microgrid can be generalized into two types: AC microgrid and DC microgrid. Compared to the typical ac microgrid architecture, dc microgrid have many advantages, it need fewer power converters, higher system efficiency and easier interface of renewable energy sources to dc system, there are no need of frequency, phase, or reactive power control. In the other hands, the consumer electronics, such as LED lighting, computer, pager, phone and so on can be more conveniently powered by dc power, so DC microgrid will be the main power supply system for the future sustainable home and buildings[1,2]. In DC microgrid, the key point of power management is to maintain the power balance between energy sources, utility units, storage device and dc loads at any time, it means, the voltage stability control is the important thing in DC microgrid[3]. In the previous literatures, several different configurations and power management strategies for DC microgrid have been reported [4,5]. The DC microgrid can be controlled in a centralized [4] based on a central controller (Data center) and communication link, so the reliability of the system is degraded. The other proposed a decentralized control methods in [5], using this approach, the system turns more flexible and expandable and can integrate more MGs without changing the control method. but in this method, all microsource using droop control to share power, it can't realize the renewable power source should provide power prior to the nonrenewable generator to the user. DC bus signaling (DBS) induce DC bus voltage level changes to realize the communications between different microsources and storage interface converters, it can maximize the use of the renewable sources, and achieved optimal control of the DC microgrid[6,7]. However, for those studies, the DC microgrid is simple, and didn't consider how to sharing power when the two microsources in the same voltage level and how to control the energy storage unit change their operation mode between droop control and maximum power point tracking(MPPT) control smoothly. This paper used the droop control based on DBS to realize the power management in proposed DC microgrid.

System configuration

The research subject is based on renewable source and energy storage. Fig.1 shows a proposed DC microgrid structure. 10kW PV arrays are connected to dc bus

through a DC/DC boost converter.A 5kW wind turbine generator with double fed induction generator(DFIG) is conncted to dc bus through a AC/DC converter. A battery as energy storage is connected to dc bus through a bi-directional DC/DC converter. Variable dc load(20kW-30kW) are connected to dc bus. The nominal voltage of dc bus is 400V, but the operating voltage range of the dc bus is chosen to be between 380V and 420V to allow power sharing and voltage regulation using the droop control. In higher voltage dc systems, fault current interruption is of particular concern. However, in the proposed DC microgrid architecture all power is fed from electronic power converters that are controllable and can provide active current limiting, thus reducing the need for electromechanical protection devices.

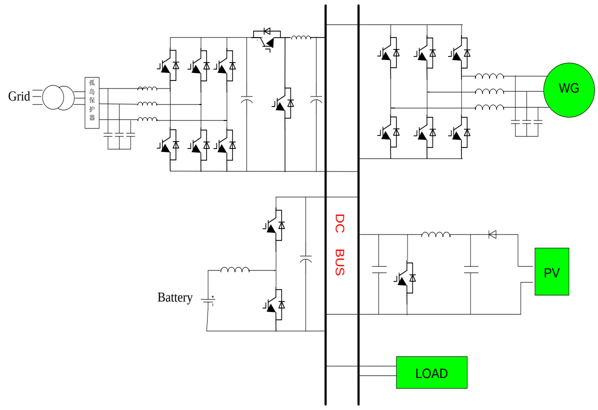


Fig 1 DC microgrid system configuration

Control law of the system

A power management strategy with DBS is proposed to maintain the power balance and stable operation of DC microgrid under any disturbance or load conditions. The operations of DC microgrid based on PV generation, Wind generation and battery are categorized into three states. Fig.2 shows the qualitative sketches of the dc output U-I characteristics for all the microsources and battery converters.

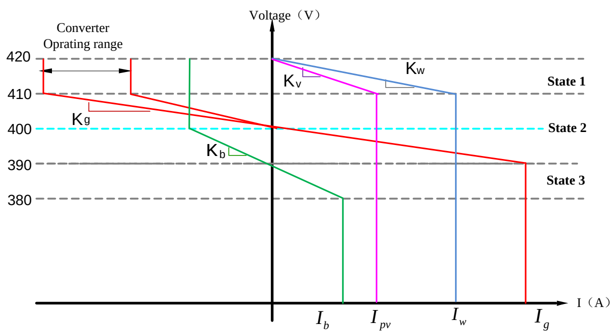


FIG 2 QUALITATIVE STATIC U-I CHARACTERISTICS OF MICROSOURCES

From the Fig.2 ,we can see that the working states of the DC microgrid is divided into three states.

State 1.This mode corresponds to ac grid connection operation via the VSC. The dc bus voltage is regulated by PV and Wind interface converter based on droop control, which means the generated PV power and wind power more than local load demands. The battery energy storage system can be charged with the constant power and the surplus power inject to the utility power grid.

State 2. In this mode, the dc bus voltage is regulated by the grid connected inverter, Wind and PV interface converter work with MPPT. In state 2.1, the DC microgrid inject power to the utility power system ,which means the local load demand less than the power which PV and Wind generated. In state 2.2, the system need more power than the renewable generation provided, the utility grid supply the deficit power.

State 3.when the local load demand power more than the largest output energy of the renewable generation provided and grid inverter , the battery converter operated on discharging mode to regulate the dc bus voltage stability as providing power is within the maximum power range of the battery system. In this state, the PV and Wind power work in MPPT mode and the grid connected inverter work in constant power mode.

The working state of system is shown in Table 1.

TABLE 1 WORKING STATE OF THE SYSTEM

state		PV	Battery	Wind turbine	Grid converter
1		Droop control	charge	Droop control	Constant power mode
2	2.1	MPPT	charge	MPPT	Droop control
	2.2	MPPT	Off	MPPT	Droop control
3		MPPT	Discharge	MPPT	Constant power mode

Important thing for this interface curve in Fig.2 is how to calculate the resistive virtual output-impedance (eg: k_w, k_v). In state 1, the PV and Wind works in parallel sharing a common load power through resistive output impedances. If there is some voltage difference, this will generate circle current. In order to reduce the circulation current, we need to adjusts the voltage reference provided to the inner current and voltage control loop based on resistive virtual output-impedance in droop control[6].

Comparing with ac microgrid, a dc microgrid is much simpler in droop control. Voltage reference value can calculate by Eq. 1:

$$V_{o\_ref}{}^{*} = V_n - kI_o \tag{1}$$

$V_{o\_ref}{}^{*}$ is the reference voltage provided to the inner current, V_n is the microsource output voltage under no load condition, I_o is the microsource output current, and k is the virtual output-impedance of microsoure and calculate by Eq. 2:

$$k = \Delta V \times \frac{V_{dc\min}}{p} \tag{2}$$

With ΔV is the voltage-changing value, $V_{dc\min}$ is the lower limit of V_{dc} in every state, p is the rated power of each microsource. When the microsource work in constant power control, the max current was calculate by Eq. 3:

$$I_{ref} = \frac{P_{\max}}{V_o} \tag{3}$$

Where $P_{\max}$ is the microsource maximum power and V_o is the output voltage of inverter which connected to the microsource .

Control structure of the system

There are four types of converters in the DC microgrid. These converters have to be coordinately controlled by with the utility grid and battery to supply an uninterrupted power to very loads under solar and wind power operate in MPPT mode in both grid connected and isolated modes. The control algorithms for these converters are presented in this section.

Bi-directional grid inverter control structure

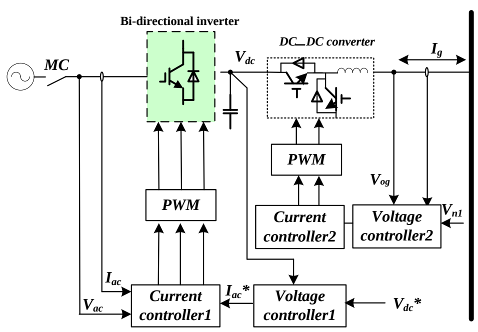


FIG.3 CONTROL STRUCTURE OF GRID INVERTER

If AC utility grid is normally operating ,the DC microgrid will be connected to AC grid through the bi-directional PWM inverter, the control method for this PWM inverter is shown in Fig.3. When the dc bus voltage between in 400V-420V, the DC microgrid energy back to grid, and the inverter current I_g is negative, while the dc bus voltage between in 390V-400V,the I_g is positive and it means the system absorb energy from utility grid. The inverter operate in droop control when dc bus voltage between in 390V-410V, and the $V_{dc}{}^{*}$ can be caculated by (1):

$$V_{dc}{}^{*} = 400 - K_g \times I_{dc} \tag{4}$$

Where K_g =0.4, and the max output current is 27A, when feedback current is bigger than 27A,we use saturation controller and control the current equals to 27A. Adopt this method, we can realized the droop control mode and MPPT mode changed smoothly.

PV panel interface converter control structure

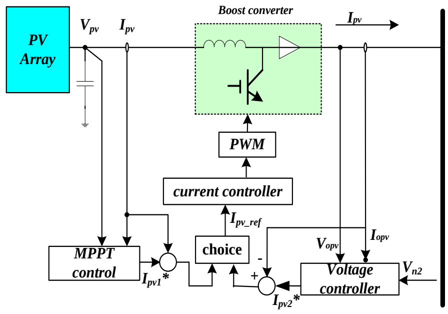


FIG.4 CONTROL STRUCTURE OF PV CONVERTER

The Boost converter for PV modules has two control modes: MPPT control and constant voltage control. The control diagram is shown in Fig.4. V_{opv} is the actual dc bus voltage and the V_{n2} is the reference voltage, when the voltage at the converter terminals V_{n2} is between the 410V and 420V, the boost converter can regulate the bus voltage by operating in the voltage droop control mode. Once it reaches the maximum available power, the converter will operate on MPPT mode as a constant power source. Same as the VI curve in Fig 2, the converter absolute current rating is shown as the vertical line defining the maximum current limit.

Wind turbine interface converter control structure

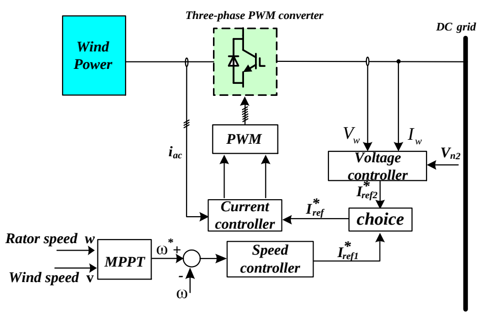


FIG. 5 CONTROL STRUCTURE OF WIND POWER

The same as PV, wind turbine converter has two operate mode: MPPT control and constant voltage control. The actual MPPT depends on the wind speed and rator speed between the zero converter output and the absolute limit. The droop slope are system designed parameters and they are selected for both the PV and the wind converter so that the voltage droop falls between 410V and 420V. In this way, the renewable generation is given the highest priority in the energy utilization sense. They are not operate on MPPT mode when the grid is not work and the load needed power is smaller than the maximum available renewable power.

Battery interface converter control structure

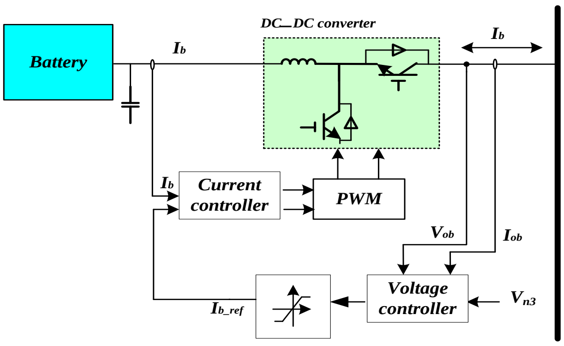


FIG.6 CONTROL STRUCTURE OF BATTERY CONVERTER

The battery is connected by a bidirectional converter to the dc bus. The control circuit is shown in Fig 6. The storage battery has three modes: charge, discharge and off. The third state is combined into a dead time running control method. When the dc bus voltage is higher than the rating voltage (400V), it means the load power is less than the renewable energy provided, the charge control can implement. Otherwise , the load power is more than renewable energy and the rating power of the grid, the battery operate in discharge mode and regulate the dc bus voltage. The control structure is two closed loops comprising a fast inner current control loop and a lower outer PI voltage control loop, it can change the charge and discharge mode of battery depending on the output current directions.

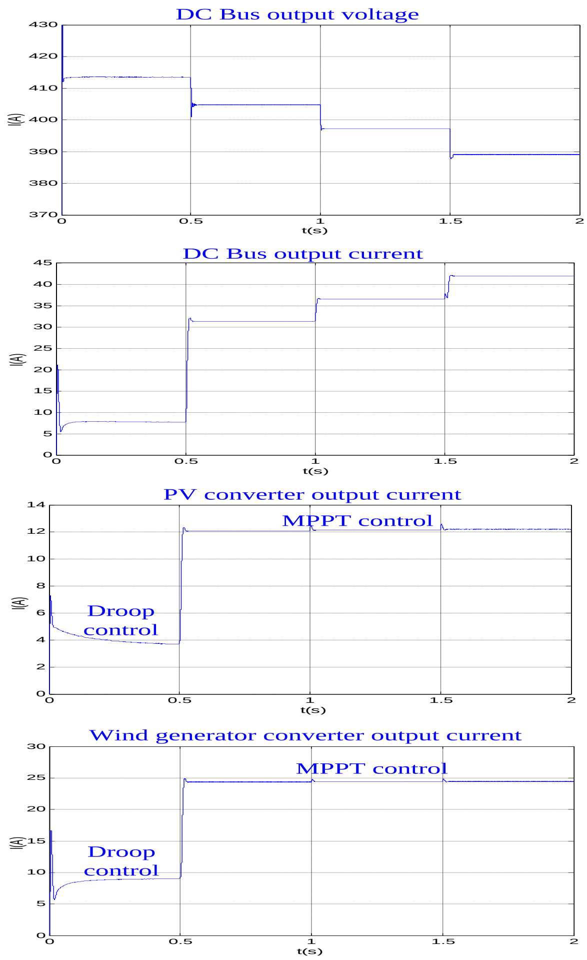
Simulation result

In order to demonstrate the proposed methods, simulation test have been carried out in this paper based on the simple DC microgrid in lab showed in Fig1. The system consists of 3 microsources, PV generation units, Wind turbine and battery unit which are connected through a DC bus. All loads are placed by resistances. The DC bus voltage is set at 380V,390V, 400V, 410V, 420V according different operation state. The system parameters are given in Table 2.

TABLE 2 . PARAMETER OF THE SYSTEM

unit	*parameter*			
PV	Rated power	5kW	Duty ratio	0.4
	Output voltage	255	Inductance	3mH
	Current Ripple	0.15	Capacitance	Pre-stage filter:100 uF Last stage filter:200uF
Battery	Rated power	10kW	Duty ratio	0.76
	Output voltage	96	Inductance	300mH，
	Current Ripple	0.15	Capacitance	700uF
Wind	Rated power	10kW	Duty ratio	0.76
	Output voltage	380V， 50Hz	Inductance	300mH，
	Current Ripple	0.15	Capacitance	700uF

The system can operated in grid connected mode and island mode, in this paper, island mode was simulated by MATLAB. Fig.7 shows the DC bus voltage, DC bus output current is the load required current when load is changed in four states, output current of PV interface converter, wind generator output cuurent, battery current, charge is negative and discharge is positive and zero means out of work.



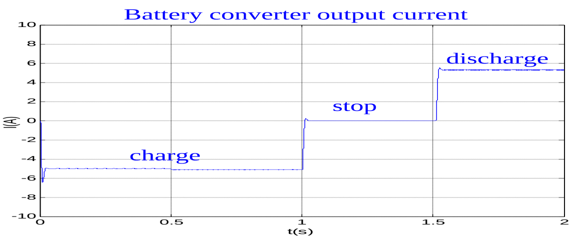


FIG.7 SIMULATION RESULTS

0s<t<0.5s : Loads are light. The output power of PV and wind is greater than the demands of loads; the storage battery will be charged. At this time, the DC bus voltage is equal to 414V. The system works at state 1. The Boost converter and bidirectional DC/DC converter share power by droop control and maintain the DC bus voltage.

0.5s<t <1s: Load power increases, the DC bus voltage is 405V, in this state, PV and Wind works in MPPT control mode, and surplus power provide to battery, the battery still work in charge state.

1s <t <1.5s: Load power still increases. The renewable power work in MPPT , and the output power equals to the requirement of load, the battery can not work in this state.

1.5s <t <2s: Load power is bigger than the total power of renewable sources. The battery starts to discharge regulating the bus voltage at its 389V in order to maintain the power balance.

Conclution

In this paper, a DC microgrid configuration based on wind turbine, PV, variable load, battery and ac grid connection is developed. A power management strategy for the DC microgrid is proposed, in which the DC bus voltage as an information carrier to distinguish different operation state of the microsources. Control structure of microsources are developed respectively. The power balance of DC microgrid under changeable load power condition is guaranteed by the proposed control method. The practical feasibility and effectiveness of the proposed control strategies have been verified by the simulation.

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